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Meeting Report: User Workshop on High-Power Lasers at the Linac Coherent Light Source

S. Hau-Riege

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Meeting Report

User Workshop on High-Power Lasers at the Linac Coherent Light Source

A two-day international workshop on the physics and integration of high-power lasers with the Linac Coherent Light Source was held in Stanford, USA, on October 1-2, 2013. The workshop was co-organized by UC Berkeley, Lawrence Berkeley, Lawrence Livermore and SLAC National Accelerator Laboratories. More than 150 scientists, including 30 students and postdocs who are working in high-intensity laser-matter interactions, fusion research, and dynamic high-pressure science came together from North America, Europe and Asia. The group discussed the most promising and important new physics experiments that will be enabled by the unique combination of high-power lasers with the world-class LCLS free-electron laser X-ray beam.

High-power laser facilities across the world can now reach petawatt (10^{15} W) laser power to drive laser targets into an extreme matter state. In this environment, the material at the laser focus is heated to high temperatures, which drives high-pressure high-density shocks, nuclear processes, as well as large magnetic and electric fields. These experiments hold great promise for laser-based acceleration of protons, electrons and ions to high energies, and for creating anti-matter and fusion neutrons. Furthermore, these processes produce secondary ultrafast X-ray and γ-ray emissions.

The LCLS X-ray beam will enable novel research projects that take advantage of its unique *in situ* probing capability to help understand the plasma and material physics within the primary laser target, and to optimize the production of laser-accelerated particles and radiation. In addition, the laser-produced radiation is in itself of great interest to heat matter for a wide range of applications including fusion and cancer research. LCLS will be able to measure these ultrafast interaction processes in secondary targets. A third class of experiments will combine LCLS with laser driven X-rays for performing X-ray pump/X-ray probe measurements with complementary spectra thus helping to resolve the ultrafast evolution of the physical properties of matter.

In four oral presentation sessions, one poster and one discussion session, workshop attendees developed the most promising high-impact science projects for the Matter in Extreme Conditions (MEC) instrument at LCLS. There was particular emphasis on prioritizing new laser, diagnostic and target developments for MEC. In addition, new collaborations have been established to best use MEC's existing and future high-power laser capabilities.

At present, the MEC instrument combines the LCLS X-ray beam with two nanosecond Joule-class lasers that can irradiate targets at intensities approaching 10^{14} W/cm^2, which can launch strong shocks or ramp-compress solids to high pressures. Of particular interest for the workshop was MEC's short-pulse laser, which will be upgraded twice during 2014, first to 25 TW (1J, 40 fs, 5 Hz) and then to 200 TW (8J, 40 fs, 0.002 Hz) peak power.

The workshop's first oral presentation session was devoted to recent experimental results obtained at MEC during its first 12 months of operation. The speakers (H. J. Lee, A. Gleason, L. B. Fletcher, B. Nagler, G. Monaco, A. Ravasio and S. Vinko) presented highly successful new experimental studies. Generally, the experiments can be classified into four classes that have used LCLS x-ray probes to characterize extreme-matter states that were produced with the nanosecond beams or by LCLS itself. These include: 1) ultrafast diffraction measurements of phase transitions in materials of interest to fusion, earth and planetary sciences; 2) spectrally resolved x-ray Thomson scattering of Compton, plasmon and ion acoustic features; 3) absorption and fluorescence spectroscopy, and 4) phase-contrast imaging of shocks and ultrafast phenomena.

During these talks, the uniformity of the laser spots was brought up, because it can affect the interpretation of experiments that require large samples. Equivalent-plane cameras were suggested for future experiments to enable users to measure the laser beam uniformity at the plane of the target and determine the evolving laser beam's phase changes from shot to shot. In addition, attendees recommended as desirable improvements increasing the total laser energy on target, laser pulse shaping and shot-by-shot pulse monitoring.

Raising these issues has had immediate impact. Shortly after the workshop, the LCLS laser engineering team demonstrated ramp-laser pulse shapes that were used successfully in material compression experiments. In addition, the team recently increased laser energy on target from 4.5J to 6 J in 3 ns long pulses.

The first workshop day concluded with an update on technologies for achieving high-power laser pulses for future high-field research and a poster session. The latter provided an opportunity for students and young researchers to present their work and ideas for novel experiments at LCLS.

The poster session further highlighted the importance of first using theory and simulations to explore the most interesting science questions computationally and then to field controlled experiments. The high-power laser-matter interaction regime is theoretically and computationally very challenging. Particle speeds approach the speed of light, so fluid-hybrid schemes often do not apply; kinetic modeling like a particle-in-cell (PIC) scheme is often required.

An example of a successful simulation approach employs adaptive particle refinement strategies that allow researchers to perform full-scale 2D simulations of an experiment at the required resolution with about 1 million CPU-hours. This can be accomplished in an adaptive scheme by creating additional simulation particles and randomizing them during the simulation.

Opening the second day of the workshops were SLAC director C. C. Kao, DOE Fusion Energy Sciences program manager A. Satsangi, and LCLS interim director U. Bergmann. After his warm welcome, Kao described the competitive landscape and access opportunities that use LCLS for research. Satsangi pointed out potential future funding opportunities for academic work at MEC through Fusion Energy Science programs, High Energy Density Laboratory Plasma Joint Program and the NSF/DOE Partnership. Bergmann reviewed recent science opportunities at all six LCLS instruments. He pointed out that MEC received its highest number of new proposals for Run 9: 35 out of 195 total for LCLS. He expects a success rate of 20-25 percent. He also challenged the MEC community to evaluate a single-pulse kicker option for increased access to the LCLS beam through a shared-operation mode.

The second oral presentation session consisted of two parts, each discussing frontier research in high-intensity laser-matter interactions. The speakers of the first part (T. Ditmire, K. Krushelnik, B. M. Hegelich) pointed towards a bright future with opportunities for transformative discoveries by using LCLS as a new precision tool for controlling and optimizing the production of radiation sources with lasers incident on thin films at intensities of 10^{18}-10^{21} W/cm^2. This class of experiments will allow producing >100 MeV protons for possible cancer therapies or for isochoric heating studies of matter, such as testing the equation of state of dense matter. Other radiation sources can drive intense x-ray sources or energetic electrons and positrons. In the talks, the speakers showed new experimental results from the Texas PetaWatt and the Michigan Hercules lasers. The high-power laser's temporal and spatial beam quality has been key for achieving efficient and stable sources. It was also suggested that the MEC's first laser upgrade include a plasma mirror to obtain a low pre-pulse level, which would be important for generating MeV proton beams.

The speakers of the second part (E. I. Moses, D. H. Froula, T. Tajima and M. Roth) focused on laser-produced radiation and particles. While Moses presented encouraging new progress towards achieving fusion conditions by inertial confinement fusion on the National Ignition Facility, the direct irradiation of matter by high-power laser-produced radiation sources has recently received wide attention for thermodynamic studies of heating, heat transport and ion stopping.

The third session described ongoing and future high-power laser developments that are particularly relevant for LCLS. In 2016, the Helmholtz International Beamline for Extreme Fields (HIBEF) instrument expects to commission a 200 TW, 10 Hz laser combined with an x-ray free electron laser beam for user experiments at XFEL, DESY, Germany. In addition, a kilo-joule class laser is being planned for studying strong shocks. Another important thrust area is the European Light Infrastructure (ELI) project, where multiple sites support a range of attosecond, high-energy-density and laser-driven particle beams. Here, multiple PW laser beams at one site will allow pump-probe studies with laser-generated x-rays.

These projects particularly benefit from lasers that can deliver high peak power, high energy and high average power. Lawrence Livermore National Laboratory is currently developing lasers projected to deliver 30 J, 30 fs, 10 Hz, 130 kW. Other high-average-power laser projects for x-ray free electron lasers are being pursued at the Rutherford Appleton Laboratory, UK, and at the Helmholtz Zentrum Dresden-Rossendorf, Germany.

At the workshop's final oral presentation session (P. Chen, J. Wark) discussed new directions in high-energy-density physics enabled by combining high-power lasers and free electron laser sources. The speakers showed a detailed study of phase transitions in solids at high pressure and explored new experiments to measure quantum electron dynamics effects, where lasers allow studies with a strong accelerating force..

The workshop concluded with a discussion session. The speakers and discussion leaders (W. Goldstein, P. Heimann, A. Thomas, M. Wei, R. P. Drake, S. Hau-Riege, P. Norris, W. White) touched many areas that included prospects for students and young researchers, access to the MEC lasers, and hardware needs to perform cutting edge research at MEC.

Goldstein presented recent work performed by successful young researchers in the field of high-energy-density science and explained the importance to continue providing opportunities in this area. Heimann followed this presentation briefly reviewing the MEC schedule and capabilities and describing access to MEC lasers. He announced a call for laser-only experiments at MEC with the purpose to demonstrate capabilities that may subsequently be applied in experiments combined with the LCLS X-ray beam. Shortly after the workshop the call has been announced on the LCLS website and all workshop participants were notified.

During the following discussion, speakers first summarized input that they received during the time leading up to the workshop particularly concerning the areas of diagnostics, targets, and optics. During the discussion the importance of improvements of the drive lasers was reiterated. In addition, with the imminent upgrade of the short pulse laser capability new diagnostics that characterize the laser and will measure the laser-produced radiation and energetic particles will become important. Many of these experiments require unique high-precision laser targets. Unique to MEC is the fact that 100 shots can be performed per day resulting in a total of 500 targets per experiment. The target discussion highlighted the need for a reliable supply source.

The competitive landscape around LCLS and MEC makes it imperative that experiments are well planned and supported by theoretical modeling and simulations. For this purpose, software packages available from universities and companies need to be made available to users. In addition, view factor software specific to support fielding experiments on MEC may be very helpful for future users.

The last part of the workshop was devoted towards ideas for future possible lasers at LCLS. They included further upgrades of laser power, high repetition rate soft x-ray lasers (10 mJ, 10s of nm, 100 Hz), and pulse train options (STUD pulses). High-power lasers approaching and exceeding PW power are of particular interest. The participants expressed preference in possible PW laser capabilities that deliver laser energy on target of order 100 J or more.

The workshop concluded with the recommendation to hold regular discussion sessions at conferences and meetings to provide the user community for a continued vehicle for input to MEC and LCLS.

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http://conf-slac.stanford.edu/hpl-2013/

Roger Falcone
Lawrence Berkeley National Laboratory
Advanced Light Source
and
University of California, Berkeley
Physics Department

Siegfried Glenzer
(chair)
SLAC National Accelerator Laboratory
Stanford Institute for Materials & Energy Sciences
High-Energy-Density Science

Stefan Hau-Riege
Lawrence Livermore National Laboratory
Physical and Life Science Directorate
X-ray Science and Technology

Figures

Figure 1: Participants at the User Workshop on High-Power Lasers at the Linac Coherent Light Source, held at SLAC National Accelerator Laboratory, Menlo Park, CA.

Figure 2: During the poster session, Félicie Albert discusses betatron x-ray production by high-power lasers with Mark Foord (researchers from Lawrence Livermore National Laboratory).

SLAC High Power Laser Workshop, Oct. 1 – 2, 2013

Summary of the theory and simulation needs to perform experiments at the LCLS/MEC instrument

Stefan Hau-Riege, Lawrence Livermore National Laboratory

XFEL facilities place a broad demand on theory and simulation capabilities. In order to utilize the scarce beam time most effectively, timely and user-friendly access to simulation and theory support is essential to prepare, execute, and analyze experiments. In particular, the high shot rates that are characteristic for XFELs demand *online* data analysis and simulation capabilities during the experiment to optimize facility utilization.

Since we are entering an unchartered regime of photon-matter interaction, we need to evaluate if current assumptions, theories and simulation codes are still valid. Therefore, a close, direct connection of modeling and theory with experiments is absolutely critical:

1) To optimally connect to experiments, simulations need to describe concrete experimental scenarios with realistic parameters, which will probably favor 2D/3D particle-in-cell (PIC), molecular dynamics (MD), density-functional theory (DFT), and rad-hydro codes initially. High-performance computing could enable MD simulation of full experiment in certain cases.
2) Since x-ray scattering and diffraction are important new tools to determine the physical properties of matter in extreme conditions, we need to perfect our analysis tools for HED-matter diagnostics, including improved models and capabilities to calculate scattering/diffraction signals from PIC/DFT/MD/hydro calculations. Such (HPC) calculations should be part of the experimental readiness for LCLS experiments.

A particular example for the new challenges is the highly non-equilibrium plasma state that can be created using XFELs, which exhibits dynamic responses, partial ionization, and high-energy electrons. All this potentially invalidates the use of standard equilibrium models to evaluate experiments performed on timescales that are shorter than relevant relaxation times. A predictive capability of the whole chain of interaction and relaxation phenomena is needed.

In order to provide preparatory and online support for experiments, modeling and theory capabilities need to be integrated in every experiment. A significant amount of knowledge and a large number of software packages are available at universities, national laboratories, and companies already. It is imperative that all this is made available and transferred to the experimental teams. This could be achieved, for example, through training classes, summer schools, and other special programs to educate junior scientists, such as post docs, and other future light source users, or through a dedicated theory and simulation support team.

During the discussion it has been claimed that a significant part of the knowledge, experience, and expertise resides outside of the US, for example in Europe.